CONSTRUCTED WETLANDS

FOR

STORMWATER MANAGEMENT:

AN ANNOTATED BIBLIOGRAPHY

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and

The Metropolitan Toronto and Region
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Report Prepared By:

Mark E. Taylor & Associates

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Conservation Authority

&

The Ontario Ministry of the Environment

By

Mark E. Taylor & Associates
160 Woodycrest Avenue
Toronto, Ontario, M4J 3B9

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DISCLAIMER

The information contained herein is provided to assist designers in evaluating the use of constructed wetlands for stormwater treatment. This information does not necessarily reflect the position and/or policies of the Metropolitan Toronto and Region Conservation Authority or the Ontario Ministry of the Environment. The use of constructed wetlands for stormwater treatment will be evaluated on a case-by-case basis.

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The Metropolitan Toronto and Region Conservation Authority (MTRCA) and the Ontario Ministry of the Environment (MOE) would like to acknowledge the initiative taken by Dr. Mark Taylor, who submitted a proposal to the MTRCA to prepare an annotated bibliography on the use of constructed wetlands for stormwater treatment. Preparation of the Annotated Bibliography and the Review Document were funded as part of the Toronto Area Watershed Management Studies (TAWMS). Knowledge gained from this investigation will be used in further studies to support the planning and design of stormwater best management practices. Liaison officers for this project included Sonya Meek (MTRCA), Gary Bowen (MOE) and Jonathan P'ng (MOE).

Introduction

In May 1991, Mark E. Taylor and Associates was contracted by the Metropolitan Toronto and Region Conservation Authority (MTRCA) to undertake a review of the wetland literature as it relates to stormwater management.

The goal of this review was to provide both an annotated bibliography and a review paper. Much of the information in the literature refers specifically to other aspects of water managment such as municipal wastewater treatment or the production of artificial wetlands for wildlife enhancement. However, many of these articles had information which was relevant to a particular area of interest and so they are included in the bibliography. The paucity of specific articles on the construction of wetlands for stormwater management was noted by Stockdale (1986). Many of the papers referred to situations very different from those in southern Ontario and were therefore not included.

Computer searches of the following databases were carried out with the help of library staff at the Royal Ontario Museum, the University of Toronto and the Metropolitan Toronto Reference Library. The following databases were searched:

- Biosis
- Waternet
- Water Resources Abstracts
- COPR 1991 NTIS government documents
- University of Toronto FELIX
- Institute of Environmental Studies U. of T. database

There are at least several thousand articles which have some bearing on the subject and the task was to obtain those which could provide the information required. Many of the obscure local government documents were not located and some articles were not included when the information appeared to be repetitive. Copies were made of articles wherever possible.

The annotations for each reference are either the author's abstract, a modification of the author's abstract, or written specifically for this bibliography. The annotations may be biased in the information provided reflecting the goals of this project.

Adams, L.W., D.L. Leedy, and T.M. Franklin. 1982. Wildlife enhancement in urban stormwater control. Pp. 384-391. *in* Stormwater Detention Facilities, Proceedings of the Conference, (W. DeGroot ed.) Henniker, NH. Published by the American Society of Civil Engineers, N.Y.

This general paper describes some of the advantages to be gained by developing stormwater wetlands in urban areas with wildlife in mind. Communities value the increased recreational opportunities obtained from wildlife viewing, and the development of artificial wetlands will mitigate somewhat the continued decline in natural wetlands in the United States. Impoundments are recommended with at least five acres of water surface. If fishes are to be introduced, lakes should be at least six feet deep.

Adamus, P.R. 1988. Criteria for created or restored wetlands. Pp. 369-372. *in* The ecology and management of wetlands. vol 2 (D.D.Hook, ed.) Timber Press, Portland Oregon.

The author discusses the relative merits of replacing lost wetlands with constructed wetlands and evaluating the quality of the constructed wetlands. He suggests that the function of the replaced wetland may not be the same as the original wetland and that detailed monitoring should be undertaken to ensure that constructed wetlands are indeed "better" than what they replace.

Allen, H.H. G.J. Pierce and R. Van Wormer. 1989. Considerations and techniques for vegetation establishment in constructed wetlands. Pp. 405-415. *in* Constructed wetlands for wastewater treatment: municipal, industrial, and agricultural. (D.A. Hammer ed.) Lewis Publishers Inc., Chelsea, Michigan.

An excellent review of the plants and techniques required to produce a constructed wetland. Salt concentrations within the water column or in the substrate has a major effect on plant species selection. A loamy topsoil is usually used for planting, while peaty soils are not advised. In marsh construction in Tompkins County, New York, muskgrass (*Chara* sp.) became dominant despite planting with a variety of species. Plant material may be obtained from either nurseries or from the wild. Wild material is generally better providing greater genetic diversity, plants more suited to the local environment and less stress. Soil plugs may also be used since they carry many seeds and propagules of other species. Care must be taken not to contaminate with noxious species. The author defines four major planting zones and indicates suitable species. Planting methods and water regime for the first year is described. After initial planting, problems are more likely to be too much water than too little; the wetland will not be stable for one or two growing seasons. Water levels can be manipulated to control growth and spread of weedy plants.

Anderson, B.W. and R.D. Omhart. 1985. Riparian revegetation as a mitigating process in stream and river restoration. Pp. 41-79. *in* The restoration of rivers and streams. (J.A. Gore, ed.) Butterworth Publishing, Boston, Mass.

The paper describes the revegetation of desert riparian systems, with the focus of the study being the banks of 450 km of the Colorado river. Preliminary studies included analyses of vegetation, avian and rodent habitats. Collection of baseline data was followed by three years of revegetation experiments. Details of costs including labour, nursery stock, equipment and materials and supplies are included. Good watersheds have a high roughness coeeficient which implies a good covering of vegetation and allows water to penetrate the soil. Native vegetation was far more suitable for bird life than introduced species.

Anderson, J.W., R.G. Riley and R.M. Bean. 1978. Recruitment of benthic animals as a function of petroleum hydrocarbon concentrations in the sediment. J. Fish Res. Board Can. 35:776-790.

Three field installation experiments were undertaken. Each consisted of clean and oiled sediments in fibreglass trays placed in the intertidal zone in Sequin Bay, Washington. The rates of hydrocarbon depuration and recruitment of benthic organisms was monitored. Individual compounds and mass spectroscopy techniques were used. The experiment was conducted for 290 days in surface oiled, coarse sediments and in finer substrates mixed with oil; rates of recruitment of benthic organisms were much higher in surface-oiled sediments. The experiments showed major biological breakdown of oils, but the rates are very dependent upon many factors including the chemical constituents, sediment type and temperature.

Bardecki, M.J. 1982. Educational use of wetlands in Ontario. Pp. 181-186. *in* Wetlands Research in Ontario - Proc. of a pre-conference session.

The educational use of wetlands has not been particularly well studied. In a random sampling of elementary and secondary schools and universities in southern Ontario the response indicated that >1500 elementary, >4500 secondary and approx 1000 university students visited wetlands as part of their studies. If one extrapolates from these figures one can estimate that between 16,186 and 36,787 children from public secondary schools visited wetlands in a year. This indicates that wetland field trips are an important facet of education in the province.

Bardecki, M.J. and N. Patterson. 1989. Wetlands: inertia or momentum? Conference proceedings. Federation of Ontario Naturalists, Don Mills, Ontario. 426 pp.

This timely book provides numerous short papers on aspects of wetlands biology, conservation, policy and maintenance.

Barko, J.W. and R.M. Smart. 1981. Sediment-based nutrition of submersed macrophytes. Aquat. Bot. 10:339-352.

The abilities of four species of submersed freshwater macrophytes to mobilize nitrogen, phosphorus, and potassium from three different sediments were examined in relation to their requirements for these nutrients. With all species, N and P were readily mobilized from each of the sediments and concentrated in plant shoots at levels well above those required for growth. However the mobilization of K from sediments was much less effective and may have limited the growth of the species. Sediments represent a large and important source of N and P for rooted aquatic macrophytes, but K is probably supplied to these plants primarily from the surrounding water. Little or no N and P were excreted from the species during growth. However, considerable quantities can be released due to plant senescence and associated decay processes. Since a large fraction of the total nutrients, and in particular N and P, released during decay may come from sediments, this mechanism represents an important mode of sediment-nutrient cycling in aquatic ecosystems.

Bedish, J.W. 1967. Cattail moisture requirements and their significance to marsh management. Am. Midl. Nat. 78:288-300.

The hybrid cattail resulting from a natural cross between *Typha latifolia* and *T. angustifolia* was studied under greenhouse and field conditions to determine the optimum soil moisture and water depth for germination, growth and vegetative reproduction. Seeds in the greenhouse required flooding for germination, but no differences were detected between water depths of 1 inch and 6 inches. Germination was reduced by 50% by storage of seed for one year at room temperature and humidity. The fastest rate of growth was recorded for plants in 1 inch of water.

Bell, A.L., E.D. Holcombe, and V.H. Hicks. 1974. Vegetating stream channels - a multipurpose approach. Soil Conserv. 40:16-18.

The alteration of stream channels is described with plans for revegetating the slopes. The general method recommended is to alternate the sides on which channelization takes place, leaving natural vegetation on the opposite banks. Such a process reduces erosion problems and assists with the rapid recovery of the stream. The minimum

amount of disturbance is made. The crown of the dredged material was planted with various grasses. The backslope was planted with a grass mixture and clusters of selected woody plants.

Benedetti, D.A., V. Rastogi and A.S. Sobek. 1990. Minimizing water treatment costs at active operations. 1990 National Symposium on Mining. University of Kentucky, Lexington. 67-213 pp.

Coal preparation plants, ore processing plants, coal tipples, refuse disposal areas, wasterock disposal areas, and slurry and tailings impoundments, have two things in common in areas where sulphides are present. They produce acid mine drainage and require extensive non-productive water treatment expenditures. Bactericides are now being used to reduce the activity of iron-oxidizing bacteria (*Thiobacillus ferrooxidans*) and thereby mitigate acid production and drastically reduce overall water treatment and management costs. Data from commercial sites are used to compare the economics of different water treatment scenarios with and without bactericides. The applications outside of mine situations might apply to coal piles associated with thermal generating or metal processing industries.

Beule, J.D. 1979. Control and management of cattails in southeastern Wisconsin wetlands. Dept. of Natural Resources Technical Bulletin No 112, Madison, Wisconsin. 38 pp.

Factors that affect cattail status in Wisconsin include physical (water levels, wave action, ice action, bottom conditions, temperature, deposition of organic materials and silt), chemical and biological factors (plant associations, fish, insects, birds, mammals). Management guidelines are directed toward controlling cattails with the ultimate goal of providing food and cover conditions for optimum production of marsh wildlife. In southeastern Wisconsin water manipulation is generally the most important management tool for cattail management. The highly manageable marsh must have a dependable, all season water supply, and be situated so that drainage is easily and quickly accomplished through an outlet structure. Management guidelines for cattail control are presented for three zones of water depths: deep water (herbicides, cutting); intermediate (cutting stems below the water on ice, crushing); and shallow (crushing, applying herbicides, creating openings, bottom contouring).

Bilby, R.E. and G.E. Likens. 1980. Importance of organic debris dams in the structure and function of stream ecosystems. Ecology. 61:1107-1113.

Removal of organic debris dams from a 175-m stretch of second-order stream at the Hubbard Brook Experimental Forest in New Hampshire led to a dramatic increase in the export of organic carbon from this ecosystem. Output of dissolved organic carbon (< 0.50 μm) increased 18%. Fine particulate organic carbon (0.50 μm-1 mm) export increased 632% and coarse particulate organic matter (> 1.0 mm) export increased 138%. Measurement of the standing stock of coarse particulate organic matter on streambeds of the Hubbard Brook Valley revealed that organic debris dams were very important in accumulating this material. In first order streams, debris dams contain nearly 75% of the standing stock of organic matter. The proportion of organic matter held by dams drops to 58% in second order streams and to 20% in third order streams. Organic debris dams, therefore, are extremely important components of the small stream ecosystem. They retain organic matter within the system, thereby allowing it to be processed into finer size fractions in head water tributaries rather than transported downstream in a coarse particulate form.

Bishop, R.A., R.D. Andrews, and R.J. Bridges. 1979. Marsh management and its relationship to vegetation, waterfowl, and muskrats. Proc. Iowa Acad. Sci. 86:50-56.

Management of Iowa's marshes is primarily aimed at waterfowl production with secondary considerations for furbearing animals and non-game wildlife. Difficulty in maintaining a marsh, which is considered optimum for avian production prompted a study to examine the linkages between duck breeding populations, muskrat (*Ondatra zibethicus*) population densities, and emergent vegetation. Blue-winged teal (*Anas discors*) populations responded to changes in the proportion of the area that contained emergent vegetation than mallards (*Anas platyrhynchcos*). Waterfowl populations were not totally dependent upon the vegetative conditions of the marsh. Muskrat populations were directly related to habitat quality but fall water levels were influential in regulating the numbers of muskrat houses and numbers of muskrats caught by trappers. The best program for waterfowl production requires control of vegetation by man-induced droughts and management of water levels until an open stage occurs. Explanation of management strategies to the public is essential together with coordination of all staff involved in marsh management.

Bond, W.K., M. Bardecki, K.W. Cox and E.W. Manning. 1988. Wetlands are not wastelands. Interim Report of Canadian Wildlife Service and Wildlife Habitat Canada. 11 pp.

Current methods of evaluating many resources inadequately portray their true environmental and economic value to society. Many wetlands have been drained because their value to society cannot be adequately demonstrated and because evaluation techniques automatically favour short-term, high value uses of the land resource. Wetlands provide a number of specific benefits to society which include water storage, sediment retention, nutrient recycling, provision of increased biodiversity, wildlife conservation, active and passive recreation, commercial plant and animal production, extraction, risk reduction, research and education, and aesthetics. It is necessary to develop techniques which evaluate the true value of wetlands and provide a guide which can be used in the planning process.

Bouldin, D.R., D.J. Lathwell, E.A. Goyette and D.A. Lauer. 1973. Changes in water chemistry in marshes over a 12-year period following establishment. New York Fish and Game Journal 20:129-146.

Changes in pH, oxygen and alkalinity were measured over a 12-year period in 20 artificial marshes. During the initial 7 years the major macrophytic vegetation was submerged, and the source of carbon for this vegetation was inorganic carbon in the water. During the last five years, emergent macrophytes dominated some marshes. These plants derived their carbon from the air, but during the winter fell into the water. During the summer decay of this vegetation exceeded the capacity of the submerged vegetation to fix inorganic carbon.

Boyt, F.L., S.E. Bayley and J. Zoltek. 1977. Removal of nutrients from treated municipal wastewater by wetland vegetation. J. WPCF 49:789-799.

A mixed hardwood swamp in Florida has been used as a filtering device for primary treated municipal wastewater for 20 years. Because of the relatively low cost of installing a trickle water supply compared to spray irrigation systems, the municipality wished to determine whether the swamp was effective in reducing contaminants. Phosphorus, nitrates and ammonia were reduced though organic carbon content was not. Faecal coliform levels dropped markedly through the swamp but were above limits for drinking water; the higher levels are attributed in part to contamination from livestock. The addition of wastewater to the swamp resulted in increased productivity of the swamp. The economic value of the swamp is discussed with savings over conventional sewage treatment of approximately $2 million over a 25 year period. The swamp is also valuable in terms of timber production.

Bradley, B.O. and A.H. Cook. 1951. Small marsh development in New York. N. Am. Wildl. Conf. 16:251-266.

Six case histories of the development of wetlands on private lands in New York State are described. Multiple use of the wetlands involved provision of more water for farmers, muskrat habitat and enhanced waterfowl habitat. Discussion about their value in flood control is also included. The importance of beavers in damming small streams to create ponds is discussed in terms of the additional provision of wetland habitat for other wildlife.

Breen, P.F. 1990. A mass balance method for assessing the potential of artificial wetlands for wastewater treatment. Wat. Res. 24: 689-697.

Artificial wetlands have been shown to have potential for treating wastewaters. An experimental artificial wetland is described together with a mass balance method for quantifying system performance, major nutrient storage components and nutrient removal mechanisms. The experimental systems were capable of a high level of performance. Percentage load removals for chemical oxygen demand, total nitrogen and total phosphorus were 86%, 95% and 99% respectively. Plant biomass was found to be the major nutrient storage compartment with plant nutrient uptake being the major removal mechanism. It was found that overall system performance could be described by a simple first order, steady state model. System design and hydrology were considered important factors in determining treatment performance. Designs must maximise wastewater-root zone contact. The experimental systems used an upflow hydraulic format to achieve this design objective.

Brenner F.J. and D.L. Hofius. 1990. Wildlife use of mitigated wetlands on surface mined lands in western Pennsylvania. Mining Reclamation Conference and Exhibition, Charleston, West Virginia April 23-26, 1990.

Twelve wetlands totalling 22.4 ha were constructed on two mine sites in western Pennsylvania to mitigate 6.6 ha destroyed by mining. A total of 24,250 wetland plants and 14,000 trees were planted on the two sites at a total cost of $17,068. Sixty species of birds representing 23 families and 18 feeding guilds, including seven species of special concern in Pennsylvania, were observed using these wetlands during the first two years. Broods of wood ducks (*Aix sponsa*), Canada geese (*Branta canadensis*), and mallards (*Anas platyrhynchos*) were observed on both mine sites. In addition 17 species of mammals, eight species of amphibians, and seven species of reptiles were observed using these wetlands. Based on these results, functional wetlands may be established on mined lands without added cost to the mine operator and their construction should be given prime consideration by the mining industry and regulatory agencies.

Broadfoot, W.M. 1967. Shallow-water impoundment increases soil moisture and growth of hardwoods. Soil Sci. Soc. Amer. Proc. 31:562-564.

Soil moisture during the growing season and radial tree growth were significantly increased by impounding winter and spring rainfall until July 1 on hardwood sites in the Mississippi Delta. In early July, the average moisture per 30 cm of soil amounted to 19.5 cm for the area that had been flooded and 13 cm for the control soil. Even late in the growing season, soil in the impoundment contained about 1 cm more moisture. Timber growth was increased by about 50%. Oxygen in the water was depleted after 15 days of dry weather, but was quickly replenished by rain.

Brodie, G.A. 1989. Selection and evaluation of sites for constructed wastewater treatment wetlands. Pp. 307-316. *in* Constructed wetlands for wastewater treatment: municipal, industrial, and agricultural. (D.A. Hammer ed.). Lewis Publishers Inc., Chelsea, Michigan.

Constructed wetlands are practical alternatives to conventional treatment of storm water run-off. Siting a constructed wetland is often dictated by the location of the wastewater source. Site selection is based on preliminary data acquisition and aerial photo interpretation, preliminary field surveys including soils and vegetation, followed by evaluation with respect to potential environmental effects and regulatory requirements. Detailed information on the hydrology of the area is essential before designs are developed. The general process of decision making and information feedback is described.

Brodie, G.A. 1990. Treatment of acid drainage using constructed wetlands experiences of the Tennessee Valley Authority. Pp. 77-83. 1990 National Symposium on Mining, University of Kentucky.

TVA is operating seven constructed wetlands systems for treating acid mine drainage at several of its reclaimed coal mines and a coal preparation site. The paper presents current information of these wetlands including evaluations of influent/effluent data, loading rates, costs, designs and systems modifications. Five constructed wetlands now operate without chemical treatment at efficiencies producing effluents that consistently meet all discharge permit limitations. TVA's experience suggests that constructed wetlands alone may be appropriate and very effective for treating weak to moderately polluted acid drainage on a long-term basis. Wetlands systems included passive designs to increase buffering capacity in the influent.

Brown, R.G. 1988. Effects of precipitation and land use on storm run-off. Water Resources Bulletin. 24:421-426.

Storm run-off quantity and quality were studied in three watersheds located near St. Paul in Ramsey County, Minnesota, from April 15 through September 15 of 1984, 1985, and 1986 to qualitatively determine the effects of precipitation and selected land uses on storm run-off. Differences in storm run-off quantity between years in an urban watershed lacking wetlands appears to be related to the average storm size during the study period of each year. In contrast, the differences in storm-run-off quantity from watersheds that contain wetlands appears to be related to total precipitation during the study period of each year. Differences in storm run-off quantity also appear to be related to the amounts of impervious and wetland area. Watersheds containing the largest amount of impervious area and smallest amount of wetland area have the largest amount of storm run-off. Differences in storm run-off quality appear to be related to the amounts of wetland and lake area. The watershed that contains the largest amount of wetland and lake area has the smallest storm run-off loading of suspended solids, phosphorus, and nitrogen. Wetlands and lakes retain the pollution loading and, subsequently lower the amount of pollution loading in storm run-offs.

Burk, C.J. 1977. A four year analysis of vegetation following an oil spill in a freshwater marsh. J. appl. Ecol. 14: 515-522.

The composition of vegetation in a freshwater marsh in Northampton, Mass. was studied for four years following an accidental oil spillage. Approximately 3,800 l of fuel oil spilled into the marsh and no detergents were used on the spill. Total plant cover, total number of species, mean number of species per quadrat and the Shannon-Weaver function progressively reduced in both the high marsh and mid marsh zones for two years following spillage. Eighteen species found before the spill were not found the following season. They were all annuals and had cover values of less than 5%. The vegetation in the high marsh and mid marsh had substantially recovered by the third and fourth years. The low marsh vegetation was apparently unaffected immediately following the oil spillage, but in succeeding years the species diversity declined and luxuriant growth of *Elodea nuttallii*, *Potamogeton crispus*, and *P. epihydrus* occurred. All of the twenty-three species in the marsh that were relatively unaffected by the spill were perennial.

Colenbrander, H.J. 1978. The rational management of hydrological systems. Pp. 363-390. *in* The breakdown and restoration of ecosystems. (M.W. Holdgate and M.J. Woodman, eds.) Plenum Press, New York.

The paper presents an overview of hydrological systems that need to be considered in water management projects. Topics include surface water systems (man made channels and lakes), subsurface water systems (ground water and soil moisture), and balancing of interests (e.g. preservation, agriculture, recreation). To arrive at rational water resource management, "social" problems are often more difficult to solve than physical and technical ones. Socio-economic models and a multilevel organization hierarchy for decision making are necessary to achieve an optimal overall water management scheme.

Conway, T.E. and J.M. Murtha. 1989. The Iselin Marsh Pond Meadow. Pp. 139-144. *in* Constructed wetlands for wastewater treatment: municipal, industrial, and agricultural. (D.A. Hammer ed.). Lewis Publishers Inc., Chelsea, Michigan.

This paper describes the construction of an artificial wetland system to treat residential sewage from a small community in Pennsylvania. The system consists of a small comminutor and aeration cell, a lateral flow marsh planted with cattails (*Typha latifolia*) in a sand medium, a facultative pond with floating aquatics (*Lemna, Sagittaria, Nuphar, Amachris*) and a meadow planted with reed canary grass (*Phalaris arundinacea*). Monitoring of the system showed BOD_5 reduction of 97% and 89% reduction of suspended solids. Faecal coliform reductions exceeded 99%. Yearly ammonia nitrogen reduction averaged 77% (93% in summer and 54% in winter). Total phosphorus was reduced on the average by 82%, with 68% in winter and 90% in summer.

Curtis, S. 1989. Wetlands and Environment Canada. Pp. 7-10. *in* Wetlands: inertia or momentum. Federation of Ontario Naturalists. Don Mills, Ontario.

This brief article provides an overview on the policy and direction being undertaken by the federal government with respect to wetlands. The author emphasises the necessity of educating the public in the value of wetlands as a part of our heritage and as a very important part of functioning ecosystems.

Dane, C.W. 1959. Succession of aquatic marsh plants in small artificial marshes in New York State. J. N.Y. Fish Game. 6:57-76.

The author describes and evaluates successional changes in vegetation of 22 small artificial marshes in the Southern Tier and Genesee-Niagara areas of New York. These areas differ in water level fluctuations, soil fertility, watershed slopes, marsh basin slopes, and water chemistry. He determines the periods between marsh flooding and invasion of vegetation, changes in species occurrence and abundance, and factors

influencing plant succession in marshes. He also discusses marsh creation in acid soil areas.

Day, R.T., P.A. Keddy, J. McNeill and T. Carleton. 1988. Fertility and disturbance gradients: a summary model for riverine marsh vegetation. Ecology. 69:1044-1054.

This study analyses five wetlands along the Ottawa river. The three main factors controlling vegetation composition were water depth, the effects of spring flooding in removing litter, and a fertility gradient produced by waves and flowing water. Four major classes of marsh types were determined dominated by *Sparganium eurycarpum*, *Eleocharis smallii*, *Scirpus americanus*, and *Typha latifolia*. Within each class, two associations could be recognized due to the amount one species dominated the vegetation. Species lists and mean abundance for the four types of association are provided. Also 16 environmental measures were taken to characterize each association. The three main factors controlling vegetation composition were water depth, the effects of spring flooding in removing litter, and the fertility gradient produced by waves or flowing water.

Demgen, F.C. 1979. Wetlands creation for habitat and treatment - at Mt. View Sanitary District, Ca. Pp 61-73. *in* Aquaculture systems for wastewater treatment: seminar proceedings and engineering assessment. (R.K. Bastian and S.C. Reed, eds.) U.S. Environmental Protection Agency, Washington, D.C.

The author describes a full scale pilot wetlands creation project consisting of a total 20.3 acres in five interconnected areas. The objective of the project was to demonstrate the feasibility of utilizing wastewater effluent to create wetlands for the benefit of wildlife and migratory waterfowl and to develop management techniques for improvement of water quality and wildlife. There is a detention time of ten days. Wetlands projects turned out to be cost effective depending on the site conditions, and energy requirements were minimal. The author also describes some of the problems with mosquitoes and how the use of mosquito fish effectively controlled their populations. A redwood swamp was also constructed and the trees grew rapidly with improved water quality at the outflow from the swamp.

Dickman, M. 1987. Impact of industrial shock loading on the aquatic plant community of a Class I wetland in regional Niagara, Ontario, Canada. Pp. 307-315. *in* Proc. Symposium '87 Peatlands/Wetlands, (Rubec, C.D.A. and R.P. Overend eds). Edmonton, Alberta.

A study of a Class 1 wetland in the Welland River area indicated a plant zonation pattern. The most pollution tolerant taxa were always tall emergents such as *Typha* and *Phragmites* while the most sensitive were always submerged aquatics. Aquatic plants and their attached microflora serve as indicators of water quality, and shock loading is consistently reflected in the flora. Downstream of toxic discharges, a dead zone was found in which all macrophytes were absent. With increasing distance from the outfall, an increasing diversity of aquatic plants was found resulting in distinct zonation patterns.

Dillon, M.M. Limited. 1990. Harrow storm and flood study. Ontario Ministry of Natural Resources 26 pp + appendices.

This report provides hydrographic information for the Harrow Storm which occurred in the Harrow area July 19-20, 1989. During a 30 hour period the centre of the storm produced at least 450 mm of rain which is far more than Hurricane Hazel. The amount of rain is probably close to the theoretical maximum which could occur in the Essex area close to the shores of Lake Erie. Total run-off volume estimates range from 16 to 140 mm, and the lowness of these values is attributed to the preceding dry period, the low level of urbanization in the area, and the possible transfer of floodwaters to adjacent watersheds along the flat Essex terrain. The report suggests that Hurricane Hazel was not that unusual for the region.

Dinges, R. 1982. Natural systems for water pollution control. Pp. 182-198. Van Nostrand Reinhold Co. New York.

The chapter on different types of natural wetlands provides an account of the use of wetlands for water purification. The author refers to the potential use of wetlands for removing nutrients and recommends approximately one hectare per hundred people for municipal wastewater. Metals are immobilized as insoluble sulphides in anaerobic conditions. The advantages of using constructed wetlands include having greater control over water flow. By constructing wetlands they can be isolated from groundwater recharge or discharge if contamination is a potential problem. Initial costs for construction of artificial wetlands is higher than using natural wetlands, but should be more cost effective over the long term.

Emerson, F.B. 1961. Experimental establishment of food and cover plants in marshes created for wildlife in New York State. J.N.Y Fish game. 8:130-144.

Plant establishment experiments were undertaken at 32 wildlife marshes in New York State. The purpose of the plantings was to establish food and cover for waterfowl. Planting areas were later evaluated in terms of factors that limit establishment of

vegetation. Planting information is provided for wild rice (*Zizania aquatica*), hardstem bulrush (*Scirpus acutus*), flowering rush (*Butomus umbellatus*), three-square bulrush (*S. americanus*), softstem bulrush (*S. validus*), river bulrush (*S. fluviatilis*), American burreed (*Sparganium americanum*), arrowhead (*Sagittaria rigida*), and smartweed (*Polygonum* spp.). The advantages of using locally obtained planting stock rather than nursery plant material is that it is more likely to be adapted to the local conditions and survive, and it is generally cheaper.

Environment Canada and Ontario Ministry of Natural Resources. 1984. An evaluation system for wetlands of Ontario south of the Precambrian shield. 2nd Edition. 169 pp.

This manual provides a method for evaluating wetlands in southern Ontario. It includes instructions on completing wetland field records including biological, social, hydrological and special features components. It introduces a scoring method which can be used to classify wetlands into classes and also a monitoring methodology which can be used for keeping standardized inventories of wetlands.

Evans, P.R., J.D. Uttley and N.C. Davidson. 1987. Shorebirds (S. Os Charadrii and Scolopaci) as agents of transfer of heavy metals within and between estuarine ecosystems. Pp. 337-352. *in* Pollutant transport and fate in ecosystems. (Coughtrey, P.J., M.H. Martin, and M.H. Unsworth eds.). Blackwell, Oxford.

Shorebirds consume large quantities of benthic intertidal invertebrates in temperate estuaries. They retain much less than 1% of the heavy metals they ingest from the soft tissues of the invertebrate food. Regular excretion of heavy metals must occur through urine, possibly nasal salt glands and the preen gland. Seasonal excretion occurs through moulting feathers and egg laying. Shorebirds may act as efficient recyclers of heavy metals, transfering them from benthic invertebrates to water and sediments within an estuary. Because many species migrate seasonally they also transfer metals to other estuaries.

Fetter, C.W., W.E. Sloey and F.L. Spangler. 1978. Use of a natural marsh for wastewater polishing. Journal WPCF 50:290-307.

The improvement in water quality of a highly polluted stream was measured after passage through Brillon Marsh, Wisconsin. The marsh is dominated by *Sparganium* and *Typha*. BOD, total P, turbidity, conductivity, ammonia, nitrate, pH, coliform bacteria, dissolved solids and suspended solids were measured upstream and downstream of the marsh. The treatment plant caused an increase of most of these

parameters. After passage through the marsh the water quality for all parameters improved significantly. Information on the seasonal hydrology is also provided.

Fredrickson, L.H. and T.S. Taylor. 1982. Management of seasonally flooded impoundments for wildlife. U.S. Fish Wildl. Serv., Resour. Publ. 148. 29 pp.

This paper discusses moist soil management to attract wildlife on man-made impoundments. Low sites where row crops are often lost to flooding are particularly well suited for moist soil management. Optimum success requires good levees, control structures for precise water manipulations and a pumping station. A group of small impoundments provides more management flexibility than a single large impoundment. The author presents guidelines for developing moist impoundments including construction costs and benefits. He also discusses integrated management plans and provides an appendix with details of some wetland species and their management.

Geis, J.W. 1979. Shoreline processes affecting the distribution of wetland habitat. Trans. N. Am. Wildl. Nat. Resourc. Conf. 44:529-542.

Wetlands along the eastern shoreline of Lake Ontario and the St. Lawrence River in New York State are maintained by changes in water level. While physical and chemical characteristics of the substrate are also correlated with community composition, they do not appear to operate independently of the hydrologic regime. High water level changes in 1973 and 1974 resulted in widespread dieback in shoreline wetland habitats. Most of the dieback occurred in emergent wetland species. Recovery has been variable, while primary production recovered rapidly. Species composition had not returned to its original state. Winter characteristics of wetlands include unique ice and snow features of importance to ecosystem stability.

Gersberg, R.M., B.V. Elkins and C.R. Goldman. 1983. Nitrogen removal in artificial wetlands. Water Res. 17:1009-1014.

The paper describes experiments using artificial wetlands to remove nitrogen from secondary wastewater. The artificial wetlands were plastic lined excavations containing emergent vegetation (cattails, rushes and reeds) planted in gravel. When methanol was supplied to provide a source of carbon, removal of nitrogen was very high (95%). Without any carbon additive, removal rates of nitrogen were much lower, approximately 25%. Experiments using additions of organic mulch were made which improved the efficiency of nitrogen removal from 60% to 86% depending upon the application rates. In many areas where natural wetlands are either geographically unavailable or protected from wastewater discharge by environmental, legal, or

aesthetic restraints, artificial wetlands offer a viable alternative for energy effective treatment of municipal and agricultural wastewater effluents.

Gersberg, R.M., B.V. Elkins and C.R. Goldman. 1984. Wastewater treatment by artificial wetlands. Wat. Sci. Tech. 17:443-450.

Artificial wetlands in Santee, California were constructed to provide secondary treatment (BOD and suspended solids removal) and advanced treatment (nitrogen removal) of municipal waste effluents. Over a one year period, 80% removal for total nitrogen and 80% for inorganic nitrogen were obtained. Removal of BOD and suspended solids were 93% and 88%, respectively. The study shows that only 6.5 ha of constructed wetlands are necessary to treat 3785m^2 of primary wastewaters to secondary treatment levels. Data on capital and operation and maintenance costs show that artificial wetlands are competitive with other treatment technologies available to small to medium sized communities.

Gersberg, R.M., B.V. Elkins, S.R. Lyon and C.R. Goldman. 1986. Role of aquatic plants in wastewater treatment by artificial wetlands. Wat. Res. 20:363-368.

The study describes the operation of a water reclamation facility in California and assesses the ability of softstem bulrush (*Scirpus validus*), common reed (*Phragmites australis*), and common cattail (*Typha latifolia*) to remove nitrogen, BOD and suspended solids in artificial wetland systems. Bulrush and reed beds had a higher efficiency in removing ammonia-N and BOD. An estimated 8 ha of artificial wetland would be required to treat 3.8 million litres of effluent per day at a significantly lower cost than conventional secondary treatment costs.

Gersberg, R.M., R. Brenner, S.R. Lyon and B.V. Elkins. 1987. Survival of bacteria and viruses in municipal wastewaters to artificial wetlands. Pp. 237-245. *in* Aquatic Plants for Water Treatment and Resource Recovery. (K.R. Reddy and W.H. Smith eds.). Magnolia Publishing Inc., Orlando Florida.

Municipal wastewater was passed through artificial wetlands consisting of 18.5 m long x 0.76 m wide x 0.76 m deep excavations, lined with plastic and containing emergent vegetation (bulrush) growing in gravel. The reduction in coliform bacteria in vegetated wetlands was greater (99%) than in unvegetated wetlands (95%). Seeded MS-2 bacteriophage used as a viral indicator was also greatly reduced (98.3%) by wetland treatment. The results indicate that artificial wetlands may serve as low cost alternatives to conventional treatment systems for reducing the load of disease causing bacteria and viruses to the aquatic environment.

Gersberg, R.M., B.V. Elkins and C.R. Goldman. 1984. Use of artificial wetlands to remove nitrogen from wastewater. Journal WPCF. 56:152-156.

Artificial wetlands, when supplemented with methanol to increase the carbon supply and stimulate denitrification showed nitrogen removal efficiencies of 94% to 97%. Plant biomass, mulched and applied to the surface of the wetland, provided a low cost alternative to methanol.

Gersberg, R.M., R.A. Gearheart and M. Ives. 1989. Pathogen removal in constructed wetlands. Pp. 431-445. *in* Constructed wetlands for wastewater treatment: municipal, industrial, and agricultural. (D.A. Hammer ed.). Lewis Publishers Inc., Chelsea, Michigan.

The U.S. Environmental Protection Agency recommends a bathing standard of 10^3 total coliform per 100 mL to ensure no adverse health effects due to body contact recreation. Coliform die-off in wetlands may be due to cell die-off, sedimentation, filtration, adsorption and aggregate formation. A vegetated wetland is more effective than a non-vegetated wetland at pathogen removal. General removal efficiencies were high (99%). Constructed wetlands make important contributions to wastewater treatment not only through their ability to reduce bacteria and viruses but also in their ability to remove suspended solids and ammonia, both of which interfere with efficient disinfection. With residence times of from three to six days, constructed wetlands are at least equivalent to, and in most cases more effective than, conventional wastewater treatment systems for the removal of disease causing bacteria and viruses.

Glooschenko, V., J.H. Archbold and J.M. Weninger. 1987. The importance of swamp wetland habitat in southern Ontario. Pp. 275-265. *in* Proc. Symposium '87 Wetlands/Peatlands. Edmonton Alberta.

The differences in values between swamps and marshes in southern Ontario is analyzed. 140 wetlands were examined of which 112 were swamps and the rest marshes. Inland swamps score as high as marshes on the OMNR evaluation scheme for most attributes but score higher for various hydrologic, biological and social values. Analysis of plant and animal lists indicate that swamps provide unique habitat for threatened and endemic biota.

Grisham, A. 1988. Public information and citizen involvement. Water Resources Bulletin. 24:449-453.

Citizens are becoming increasingly concerned about governmental decisions that affect their lives and are demanding more information about governmental activities, including information about water resource issues. Because of active citizen interest and involvement, the role of public information is becoming more important.

Government officials and professionals should recognize that public information efforts also play an important role in achieving increased credibility and respect for their agencies. Two of the most flexible and cost effective ways to get information to the public are through publications and public meetings. Both can be easily adapted to suit the ends of specific audiences and projects.

Successful public information programs can be carried out at relatively low cost, but require substantial amounts of time and energy. An effective public information program can play a significant role in improving the quality of governmental decisions through the increased involvement of the citizenry.

Gosselink, J.G. and R.E. Turner. 1978. The role of hydrology in freshwater wetland ecosystems. Pp. 63-78. *in* Freshwater wetlands. Ecological processes and management potential. (R.E. Good, D.F. Whigham and R.L. Simpson, eds.) Academic Press, New York.

This review paper describes the basic process occurring in wetlands and relates them to the energy levels associated with water movement. A discussion of the maturity of wetlands and ecological succession is undertaken in context of sediment accumulation and nutrient fluxes. The hydrologic regime is the most important characteristic of wetlands, and by monitoring wetlands we can better understand their functioning.

Greer, R.B. 1979. A tree planting trial at Loch Garry (Tayside region) aimed at habitat improvement for fish. Scottish For. 33:37-44.

Leaves from deciduous trees are a major source of food for aquatic invertebrates, and may make a greater contribution to the productivity of upland waters than aquatic plants. The destruction of riparian woodland is likely to have had an adverse effect on the production of aquatic invertebrates and hence fish which depend on these animals for food. Deciduous woodland is being re-established to provide an indirect source of food for fish. Results of the planting trial and approach taken to tree planting is described.

Guntenspergen G.R., F. Stearns and J.A. Kadlec. 1989. Wetland Vegetation. Pp 73-88. *in* Constructed wetlands for wastewater treatment: municipal, industrial, and agricultural. (D.A. Hammer ed.). Lewis Publishers Inc., Chelsea, Michigan.

This is a general paper on various plant groups and their usefulness in wastewater treatment. Floating aquatics and emergents provide the most effective plants for stripping nutrients and contaminants from the water column. Submergent plants are not as useful though they may play a role. No single set of species is likely to be useful for all sites and conditions and relatively few species have so far been checked. A list of plant species tested in constructed wetlands is given. Short lived species which strip nutrients may then release them to the water body when they decay and therefore do not represent a mechanism for large scale removal of nutrients unless the plants themselves are harvested. Gravel bed substrate may assist in stripping of nutrients.

Hammer, D.A. and R.K. Bastian. 1989. Wetlands Ecosystems: Natural Water Purifiers?. Pp 5-19. *in* Constructed wetlands for wastewater treatment: municipal, industrial, and agricultural. (D.A. Hammer ed.). Lewis Publishers Inc., Chelsea, Michigan.

This article provides an overview on the use of constructed wetlands for treatment of contaminated waters. The advantages of wetlands include low cost and low maintenance, but in many cases they require a large area. Important points mentioned include the necessity for seasonal changes in the level of the water table, permitting anoxic and aerobic conditions in the substrate. This permits a much wider variety of organisms. Although constructed wetlands may be planted with relatively few species, in the space of a few years colonization by other species has been dramatic. Advantages of wetlands as buffering systems, desynchronizing peak contributions and serving as discharge areas are listed. The advantage of marshes lies in their relatively quick establishment (a few years) as opposed to the development of swamps (5-20 years). The importance of natural microbes acting as predators on pathogens is mentioned together with the locking up of heavy metals and other pollutants. This is a good introduction to the subject.

Harris, S.W. and W.H. Marshall. 1963. Ecology of water-level manipulations on a northern marsh. Ecology 44:331-343.

The paper describes an experiment to establish emergent vegetation in a drawdown area on the Agassiz National Wildlife Refuge in north-western Minnesota. The primary objective was to revegetate open water after planned drawdowns. Various pool conditions were available to study drawdown effects. Results are depicted in a table showing marsh type, species composition, density, exposure time, soil type, rate

of superficial drainage, and amount of algal debris. The authors discuss the maintenance of emergent marshes with 1 to 2 year drawdowns at 5 and 10 year intervals.

Heede, B.H. 1979. Deteriorated watersheds can be restored: a case study. Environ. Manage. 3:271-281.

This project in west-central Colorado demonstrated that a watershed dissected by a dense gully network can be stabilized and rehabilitated. Check dam systems, aided by improved vegetative cover through reduced cattle grazing and plantings, stabilized not only the structurally treated gullies, but also gullies within the network that were not structurally treated. Comparison with untreated gullies outside of the project area showed that the outside gullies widened three times as much as the structurally untreated inside gullies. Statistical analysis indicated that precipitation was normal during the treatment and evaluation period. Check dams decreased gully depth by accumulating sediment deposits. In turn, gully bank stabilization was hastened and alluvial aquifer volumes increased. This increase, plus higher infiltration rates as a result of denser vegetation, led to renewed perennial streamflow after seven treatment years. Within 11 years after treatment, check dam systems and improved vegetation reduced sediment loads in the flows by more than 90%, providing a substantial benefit to farmlands and ponds downstream.

Herskowitz, J. 1986. Listowel Artificial Marsh Project Report. Ontario Ministry of the Environment Project No. 128 RR. 253 pp.

This report provides the technical information about the pilot secondary treatment of municipal sewage in Listowel, Ontario. Sewage pretreatment involved an aerated facultative cell with a 30 day hydraulic retention time. The water flowed through different types of constructed wetland vegetated with emergent aquatics (*Typha* spp.). Hydraulic retention time in the marshes was effectively regulated by adjustments of water depth (<10 cm in summer, and >30 cm in winter). The project was monitored for four years, and for the most part resulted in water outflow of acceptable standards. The four year annual average effluent quality in the channelized marshes receiving lagoon effluent was BOD 7.6, SS 9.2, TP 0.5 and TKN 6.2 mg/L. Phosphorus removal was much reduced after the first year and phosphorus removal prior to treatment of wastewater by constructed wetland was recommended for Port Perry, Ontario.

Horner, R.R. 1988. Long-term effects of urban stormwater on wetlands. Pp. 451-466. Proceedings of the Engineering (Fourdelon) Conference on current practice and design criteria for urban quality control. Potosi, MO. Published by ASCE, NY. NY.

This paper outlines the work which led up to the production of the annotated bibliographies by Stockdale 1986 and Stockdale and Horner 1987. This resulted in undertaking a survey of 73 palustrine wetlands in King County. Forty-six of these wetlands receive urban run-off and 27 do not. A program of sampling the wetlands followed which involved measuring floral and faunal characteristics together with water and soil chemistry. Soils were measured for texture, organic content, pH, Redox potential, Pb, Cd, Zn, Cu, total phosphorus, total nitrogen, microtox, carbon dioxide evolution, ATP, and microfauna. The water column was examined for pH, faecal coliforms and enterococci. Plant analysis involved determining cover abundance and the presence of Pb, Cd, Zn Cu in tissue. Faunal analysis was confined to aquatic invertebrate counts and the sightings of other species. The wetlands showed considerable within-group variability which reduced the ability to discern differences between them. The major differences appear to be in the water column bacterial counts and the presence of heavy metals in the urban wetlands. If the wetlands are screening out large numbers of bacteria they contribute to downstream water quality improvement but this was not investigated.

Howard-Williams, C. 1985. Cycling and retention of nitrogen and phosphorus in wetlands: a theoretical and applied perspective. Freshwater Biology. 15:391-431.

This review considers the internal fluxes and movements of nitrogen and phosphorus in wetlands. The dynamic nature of nutrient cycling is emphasised. Wetlands as nutrient sinks in the treatment of wastewaters was considered as a major applied function. Various perspectives of wetland ecosystem functioning are discussed including successional time scales, exchange equilibria, storage and throughflow and the nutrient spiralling concept. Processes of evapotranspiration, nutrient movements and seasonal floods are considered to have significant effects on nutrient concentrations. The paper provides a good academic view of wetlands as nutrient stripping systems, and critically points out long term problems which may arise.

Huber, W.C., J.P. Heaney, K.J. Smolenyak and D.A. Aggidis. 1979. Urban Rainfall-Run-off-Quality Data Base. U.S. Environmental Protection Agency. EPA-600/8-79-004.

Urban rainfall-runoff-quality data gathered by others have been assembled on a storm event basis for 25 catchments in urban areas in the U.S. as well as Windsor, Canada. The report includes a statistical analysis of data from all catchments that include

quality sampling. For each storm event the clock times, duration and volume of rainfall and run-off are given. A number of Canadian contacts are given in the report.

Hynes, H.B.N. 1960. The biology of polluted waters. Liverpool University Press. 202 pp.

This text on the biology of aquatic systems and how they are affected by contaminants is a classic introduction to the subject. The author provides an account of the history of water pollution followed by descriptions of the physical and chemical effects of pollutants on aquatic ecosystems. References to the literature prior to 1960 are comprehensive and worldwide in scope.

Johnson, B.T. 1986. Potential impact of selected agricultural chemical contaminants on a northern prairie wetland: a microcosm evaluation. Environmental Toxicology and Chemistry. 5:473-485.

An aquatic, multi-component microcosm simulating a northern prairie wetland was used to assess the potential effects of six extensively used agricultural pesticides (carbofuran, fonofos, phorate, atrazine, treflan and trialate) on this habitat. Static acute toxicity tests with *Daphnia magna* and *Chironomus riparius* suggested that carbofuran, fonofos, and triallate were very toxic to aquatic invertebrates. Atrazine significantly reduced gross primary productivity and inhibited algal and macrophytic growth.

Johnston, C.A., G.D. Bubenzer, G.B. Lee, F.W. Madison and J.R. McHenry. 1984. Nutrient trapping by sediment deposition in a seasonally flooded lakeside wetland. J. Environ. Qual. 13:283-290.

Sediment and nutrient retention in a seasonally flooded wetland was studied in rural Wisconsin. The wetland was inundated during spring run-off and during storm events. Nutrients associated with sediments were deposited on the extensive flat areas and levees, but under low water flows the water and associated sediments travelled through a narrow stream to the lake. Sediment deposition is an important mechanism for immobilizing nutrients carried in flood waters, and this served to trap nutrients more effectively than when nutrients were taken up by vegetation. Nutrient release from vegetation decay did not immobilise nutrients as effectively as when they were bound in sediments. Despite the benefit of wetlands to lake water quality, nutrient uptake by wetlands is only a stopgap measure and wetlands should not be considered as a panacea for eliminating surface water quality problems.

Kadlec, R.H. and J.A. Kadlec. 1978. Wetlands and water quality. Pp. 436-456. *in* Wetland Functions and Values: the State of our Understanding. (Greeson P.E. et al. eds). American Water Resource Association, Minneapolis, MN.

This review paper considers the major components of wetlands in modifying water quality. The hydrology of a wetland must be understood before one can quantify other parameters. The chloride ion may be used as an indicator for determining water budgets. The inflow and outflow of nitrogen and phosphorus to wetlands varies considerably, and information on the standing crops of N and P is provided for 13 wetlands. A model for the role of macrophytes in nutrient cycling is given and the movement of other dissolved substances is discussed. Aquatic and semi-aquatic plants may absorb heavy metals into their structure, and these may be passed along food chains or they may be deposited in sediments. Complex organic compounds may be broken down by microbial activity or taken up by higher plants. Data on the efficiencies of wetlands at reducing pathogen concentration is highly variable. The need for longer term studies is emphasised.

Kadlec, R.H. 1979. Wetland tertiary treatment at Houghton Lake, Michigan. Pp. 101-139 *in* Aquaculture systems for wastewater treatment: seminar proceedings and engineering assessment. (R.K. Bastian and S.C. Reed, eds). U.S. Environmental Protection Agency, Washington, D.C.

For five consecutive summers, secondary wastewater was discharged to areas within a peatland in central Michigan. All nitrogen and phosphorus was removed from 100,000 gallons per day within a five acre area. The maximum water depth increases were 10-15 cm, at the centre of the discharges. Some dissolved ions such as chloride flowed through the treatment area with very little change; other parameters such as pH changed rapidly to reach background values. No soil erosion or plant mortality occurred. Suspended solids were deposited close to discharge and odour problems were slight. No net virus or coliform populations were transported to the wetland. Animal populations have not yet responded to the discharge.

Kadlec, R.H. 1987. Northern natural wetland water treatment systems. Pp. 83-98. *in* Aquatic Plants for water treatment and resource recovery. (K.R. Reddy and W.H. Smith eds.). Magnolia Publishing Inc., Orlando, FL.

The performance of northern natural wetlands in the treatment of secondary municipal wastewater is described and ten systems compared. The hydrologic regime is shown to be a controlling factor and generally wastewater quality is improved by passage through the wetland. Winter operation is possible, but efficiencies are reduced. Sediments are retained by wetlands but are also generated by microorganisms leading to export of particulates in outflow waters. Biomass increases and there are distinct

changes in species composition of the wetland tending towards cattail predominance. This also results in changes in faunal composition with a reduction in diversity.

Kadlec, R.H. 1989. Hydrologic Factors in Wetland Water Treatment. Pp.21-40. *in* Constructed wetlands for wastewater treatment: municipal, industrial, and agricultural. (D.A. Hammer ed.). Lewis Publishers Inc., Chelsea, Michigan.

This paper describes some of the hydrologic factors which must be borne in mind when assessing the degree of treatment of contaminated waters. Basic hydrologic formulae are introduced. Evapotranspiration from vegetation in a wetland may be greater than from an equivalent area of open water, and varies greatly with latitude and season. Even in northern climates, all applied wastewater can be evaporated during a dry summer season. There are no significant differences between plant species. The wetland may also act as a catchment area for water, diluting concentrations of pollutants and giving false readings on the efficiency of the wetland. Frictional effects associated with water flow through a gravel or rock substrate differ from flow through stems and litter above ground. In the former case, system overloads can cause emergent overland flow near the entrance. In the latter, high vegetation densities can increase depths above planned weir settings. Both effects are forms of water mounding.

Kadlec, R.H. and D.L. Tilton. 1979. The use of freshwater wetlands as a tertiary wastewater treatment alternative. CRC Critical Reviews in Environmental Control. 9:185-212.

The use of wetlands for tertiary wastewater treatment is described in terms of abiotic and biotic factors. The efficiency of wetlands at removing N, P, SS, BOD, COD, and heavy metals is discussed. The biological improvements due to the removal of bacteria and viruses as well as the impacts on vegetation and animals is described with complete references. Societal factors such as economics, political and regulatory factors and aesthetics are included in the analysis. The author suggests that wetlands are strongly buffered against the stress of treated wastewater and that dissolved nutrients may be effectively removed in many cases. The impacts on natural wetlands are site specific and changes in plant and animal communities range from the barely detectable to highly significant.

Keddy, P.A. and T.H Ellis. 1985. Seedling recruitment of 11 wetland plant species along a water level gradient: shared or distinct responses? Can. J. Bot. 63:1876-1879.

This study was designed to determine what the controlling influences were on the germination of 11 species of wetland plants. Seeds of the following species were allowed to germinate on a sand substrate along a gradient of water depth from 10 cm above to 5 cm below the water surface. *Scirpus americanus, S. validus, Sagittaria latifolia, Typha angustifolia,* and *Lythrum salicaria* showed no significant response to the water gradient while *Spartina pectinata, Polygonum punctatum, Bidens cernua, Acorus calamus, Alisma plantago-aquatica* and *Eupatorium perfoliatum* did. Most species showed some recruitment at all water levels suggesting that they have broad tolerances for water depth at the recruitment stage of their life history.

Korschgen, C.E. and W.L. Green. 1989. American Wildcelery (*Vallisneria americana*): ecological considerations for restoration. U.S. Fish and Wildlife Service, Northern Prairie Wildlife Research Centre. 24 pp.

The success of vegetation management programs for waterfowl is dependent on knowing the physical and physiological requirements of the target species. Lakes and riverine impoundments that contain an abundance of wildcelery have traditionally been favoured by canvasbacks and other waterfowl. Information on the ecology of the wildcelery together with its use in wetland restoration projects is discussed.

Krull, J.N. 1970. Aquatic plant-macroinvertebrate associations and waterfowl. J. Wildl. Manage. 34:707-718.

An ecological study was conducted to determine the association of macroinvertebrates with 12 species of submerged aquatic plants common in central New York State. The abundance and kind of animals associated with each plant species and with their substrates was determined. A total of 114 different taxa were collected. Some plants harboured a larger biomass, greater numbers, and a greater taxonomic diversity than other hydrophytes. Three plant species harboured 60% of the animal species. Macroinvertebrates appeared to be many more times abundant in vegetated areas than in non-vegetated areas. On the average, 1 g of animal life was found associated with 100 g of plant life. Diversity was greatest in duckweed (*Lemma*) and waterweed (*Elodea*) and lowest in water milfoil (*Myriophyllum*) and hornwort (*Ceratophyllum*). Hydrophytes believed to be poor waterfowl food plants such as *Elodea* are actually important to waterfowl production because they harbour large quantities of macroinvertebrates, which provide a source of animal protein for many species.

Kubichek, W.F. 1940. Collecting and storing seeds of waterfowl food plants for propagation. Trans. N. Amer. Wildl. Conf. 5:364-368.

This article discusses methods for collecting and storing seeds of waterfowl food plants. It provides useful advice on harvesting operations using combine harvesters. Dry and wet storage of seeds, and timing of harvest are given for alkali bulrush (*Scirpus maritimus*), wild millet (*Echinochloa crusgalli*), Pennsylvanian smartweed (*Polygonum pennsylvanicum*), sago pondweed (*Potamogeton pectinatus*), bush pondweeds (*Naias* spp.), common wigeonweed (*Ruppia maritima*), duckpotatoes (*Sagittaria* spp.), and annual wildrice (*Zizania aquatica*).

Lacki, M.J., J.W. Hummer and H.J. Webster. 1990. Diversity patterns of invertebrate fauna in cattail wetlands receiving acid mine drainage. Mining and Reclamation Conference and Exhibition, Charleston, West Virginia, April 23-26, 1990.

Invertebrate diversity patterns at a three-celled, 0.3 ha, cattail wetland, constructed in 1985 to receive mine drainage, were surveyed during May and June in 1988 and 1989. Three nearby sites, of volunteer cattail cells, were also examined as a control. Benthic invertebrates were collected using an Eckman dredge and volant insects were obtained with sticky traps covered with tangle trap. Dredge samples were examined at the family level and sticky traps at the ordinal level.

The numbers and diversity of invertebrates from the constructed wetlands were lower than the control sites. Significantly fewer taxonomic families as well as lower numbers of invertebrates occured in the constructed wetlands than in the control sites. Shannon-Weaver diversity indices showed that the constructed wetland supported a simpler community relative to the other sites. However, the number of invertebrate families increased from three in 1988 to eight in 1989 in the constructed wetlands.

The paper describes the statistical methods used for evaluating differences between the constructed and natural wetlands.

Lahiti, T. 1977. Restoration of a small suburban southern Wisconsin wetland. Pp. 136-163. *in* Wetlands: ecology, values, and effects. Proceedings of the Waubesa conference on wetlands. (C.B. Dewitt and E. Soloway, eds.). University of Wisconsin, Institute of Environmental Studies, Madison.

Four wetlands in southern Wisconsin were examined for wetland vegetation dynamics. A wetland restoration project for a highly disturbed site in Madison was undertaken. Plant material was obtained from a nursery. Development was rapid for most species, and all had high survival rates. Emphasis was placed on choosing plants

that commonly grow in similar settings and on planting them in specific relation to water levels.

Lathwell, D.J., D.R. Bouldin and E.A. Goyette. 1973. Growth and chemical composition of aquatic plants in twenty artificial wildlife marshes. New York Fish and Game Journal. 20:108-128.

Ten years after construction, 20 (half acre) marshes in New York State were evaluated in terms of aquatic plant growth and chemical composition in relation to substrate preparation. The dominant species and marsh productivity were determined. Total above ground biomass for emergents generally varied from 300 to 800 g/m^2. This was three to five times greater than that of submergents. Prevalent emergents were bulrush (*Scirpus*) and cattail (*Typha*); *Chara* was the dominant submergent. Standing crop was inversely related to water depth and was 690-833 g/m^2 at 0.3 m (1.0 foot) and 208-355 g/m^2 at 0.9 m (3.0 feet). Total ash, iron, manganese, nitrogen, phosphorus, calcium and potassium were measured.

Lee, G.F., E. Bentley and R. Amundson. 1975. Effects of marshes on water quality. Pp. 105-127. *in* Coupling of land and water systems. (A.D. Hasler ed.). Springer-Verlag, New York.

This paper reports on the effect that several marshes in Wisconsin have on water quality. Descriptions of the marshes are provided and for the most part they are associated with agricultural lands. An attempt to monitor nutrient status of waters entering and leaving the marsh was confounded by a lack of data on the complex hydrology of the marshes. Because they were, for the most part, areas of water discharge, the dilution of contaminated waters may have been as important a factor as the nutrient stripping function of the marsh. Since marshes are generally areas of water discharge, the efficiencies of marshes at reducing nutrient loads is often distorted by a lack of understanding of the hydrology of the area.

Litchfield D.K. and D.D. Schatz. 1989. Constructed wetlands for wastewater treatment at Amoco Oil Company's Mandan, North Dakota refinery. Pp. 233-237. *in* Constructed wetlands for wastewater treatment: municipal, industrial, and agricultural. (D.A. Hammer ed.). Lewis Publishers Inc., Chelsea, Michigan.

A series of cascading ponds were developed for cleansing of wastewater from a refinery in North Dakota. Ponds were constructed by building dams across natural drainage channels. Water levels are controlled by siphon lines, drain lines, and a series of culverts with slip gates. Cattail, bulrush and a mix of other wetland plants naturally invaded the lower ponds. Normally water flow is through six of the 11

ponds, with a treatment area of 16.6 ha. Five ponds (19.1 ha) are dedicated to wildlife management, providing diversion or holding capacity during heavy rain or snowmelt or an unexpected contaminant problem. Most substances are reduced 36-99% in primary lagoon, and concentrations further reduced by 70-100% in the cascading pond system. Volume of wastewater is affected by evaporation, percolation, stormwater run-off, and influent from natural springs in the area. In 1979, a survey on chromium, copper, iron, nickel, lead and antimony showed that most of the reduction in concentration occurred in a 0.8 km earthen canal between the primary lagoon and the first pond of the system. This canal had a heavy growth of vegetation including cattails and bulrushes. Wildlife habitat was enhanced by creating islands in some of the ponds and planting 50,000 trees and 30,000 fruit bearing trees and shrubs. 184 species of plants have been identified. Ponds were stocked with rainbow trout, bass, and bluegill. Trout taken for necropsy analysis were all normal. Numerous other mammals and birds use the area.

Livingston, E.H. 1989a. Use of wetlands for urban stormwater management. Pp 253-262. *in* Constructed wetlands for wastewater treatment: municipal, industrial, and agricultural. (D.A. Hammer ed.). Lewis Publishers Inc., Chelsea, Michigan.

This paper provides two case studies in Maryland and Florida where wetlands have been used for storm water cleaning and control. It emphasises that little data is available for stormwater control and management and the situation is different from polishing treatment for regular water treatment. Nutrient concentrations in wastewater and stormwater may differ by a factor of 10 or more and treatment efficiencies of wastewater wetlands may not be applicable to stormwater treatment. Stormwater management should consist of several treatments, of which wetlands might be one, the more BMPs in the system the better the performance. The first flush of a rain event (approx. 2.5 cm) carries 90% of pollution from a storm event. Treatment of that run-off will help minimize water quality effects of urban stormwater. Establishing wetland hydroperiod is of primary importance because this determines the form, nature and function of the wetland. Details are given for a Maryland wetland, with species and planting densities as well as design criteria. Unacceptable species are also listed with cattails and reeds listed. Little is known of the bioaccumulation of heavy metals or other toxics typical of stormwater.

Livingston, E.H. 1989b. The use of wetlands for urban stormwater management. Pp. 467-489. *in* Proceedings of the Engineering Foundation Conference on Current Practise and Design Criteria for Urban Quality control. Potosi, M.O. Publ. by ASCE, NY.

This review paper compares the use of constructed and natural wetlands for stormwater management. The paper provides a comprehensive review of the

Maryland and Florida constructed wetlands and provides planting and design instructions for constructed wetlands as well as discussing the limitations of such structures. Many questions are raised for which answers should be sought in future.

Loftis, J.C. and R.C. Ward. 1980. Water quality monitoring - some practical sampling frequency considerations. Environmental Management. 4:521-526.

Water quality monitoring involves sampling water at certain frequencies so that changes in water quality are detected and seasonal as well as daily differences can be discriminated. There is a trade-off between sampling very frequently with higher associated costs, and sampling less frequently and losing important data. This paper looks at the frequency of sampling from a statistical point of view. The results indicate that three time periods can be distinguished. 1) At high sampling frequencies with serial correlation being significant, 2) with 10-30 samples taken every year where seasonal and serial correlations tend to cancel each other, and 3) with less than 10 samples a year where seasonal variation plays a dominant role.

Lyon, J.G., R.D. Drobney and C.E. Olson. 1986. Effects of Lake Michigan water levels on wetland soil chemistry and distribution of plants in the Straits of Mackinac. J. Great Lakes Res. 12:175-183.

The effects of short-term flooding on the nutrient status and species composition and extent of wetlands were studied in Lake Michigan. Flooding results in anaerobic soil conditions and increased availability of nutrients for plants. The density of plants was greatest where the topographic conditions and water levels resulted in flooding between 50% and 85% of the growing season. The extent of wetlands depended upon lake levels and varied from approximately 45 ha (July 1974, water height 177.18m) to 228 ha (March 1964, 175.47m). Wetland plant distributions are related to elevation, duration of flooding and soil chemistry. Infrequently flooded areas had a greater number of species than more frequently flooded sites.

Madsen, C. 1986. Wetland restoration: a pilot project. J. Water and Soil Conservation. 41:159-160.

This popular article describes the agencies involved and methods used to reestablish wetlands in Minnesota. Landowners were able to contact the Fish and Wildlife Service and a goal of 2000 acres of wetland re-establishment was set. With cooperation of wildlife organizations such as Ducks Unlimited, areas of old wetlands were redeveloped. Landowner interest in the program was high and many farmers were keen to retire marginal lands to wetlands.

Marble, A.D. and M. Gross. 1984. A method for assessing wetland characteristics and values. Landscape Planning. 11:1-17.

This paper describes methods for assessing wetlands on three simple characteristics: substrate composition, topographic position and size. 385 wetlands in New Canaan, Connecticut were examined and compared statistically. It was found that 72% of the wetlands were small, > 1 ha., 55% of the streams had inflow and outflow, 30% had outflow only while 15% were hydrologically isolated. Of the 128 wetlands having high value for sediment and erosion control, 68% were found to be in valley wetlands, 14.5% on hillsides, and 17.5% on hilltops. Wetlands that were relatively flat had greater capacity to reduce flood peaks than those on slopes, and flood control was greatest for areas immediately downstream from the wetland. Larger wetlands had greater value for wildlife than small wetlands. The educational value of wetlands was not assessed but was deemed to be significant.

Marsalek, J. 1977. Monthly pollution loads in urban run-off from the Malvern test catchment. Unpublished Report, Hydraulics Research Division, Canada Centre for Inland Waters, Burlington, September 1977.

A regression model of urban runoff quality was selected as the best means of determining the pollution loads in runoff from the Malvern catchment. The model is based on the antecedent dry weather period and pollution accumulation rates which were derived from the observations on the Malvern catchment. Monthly pollutant loads were then computed directly for a number of constituents, and for others the loads were derived indirectly by statistical correlation. A seasonal adjustment of loads resulted in a larger variation in the loads during the year. For BOD, nitrogen and phosphorus, solid loads were also calculated by means of empirical formulas. These loads were found to exceed the liquid (dissolved) loads. Street sweeping was found effective in reducing the monthly pollution loads. For a frequency of once per week and the cleaning efficiency of 0.7, sweeping reduced the monthly runoff loads by about one third.

Finally, the monthly loads presented contain large uncertainties because of the limitations of the basic supporting data and the lack of understanding of the processes controlling the quality of urban runoff.

Marsalek, J. 1978. Abatement measures for pollution due to urban runoff. Unpublished Report, Hydraulics Research Division, Canada Centre for Inland Waters, Burlington. April 1978.

Three levels of abatement of pollution due to urban runoff were investigated. Street cleaning, which represents a source control measure, was considered as a first level

abatement measure. The costs and pollution abatement effectiveness of street cleaning were established. The second level abatement measures consisted of runoff storage and treatment by sedimentation. The third level abatement measures consisted of runoff storage and advanced treatment. The effectiveness and costs of the second and third level measures were derived by modification of the data which were established by the American Public Works Association for the province of Ontario.

Marsalek, J. and B. Greck. 1984. Toxic substances in urban land runoff in the Niagara River area. Unpublished Report, Hydraulics Division, Canada Centre for Inland Waters, Burlington. January 1984.

This report provides information on the loadings of 51 persistent toxic substances in urban runoff in the Niagara area. For each substance studied, frequencies of occurrence and mean event concentration have been determined. In sediment samples, the most widespread substances were trace elements (100% frequencies observed for As, Cu, Pb, Se, and Zn), PCB's, some organochlorine pesticides (p,p' -DDE -59%, a-BHC - 53 %, a-chlordane - 50% - 50% y - chlordane - 40% and p,p' DDT - 35%), and several chlorinated benzenes. Polyaromatic hydrocarbons were rarely detected. In stormwater samples, the highest frequencies were found for some trace metals (Hg - 100%, Zn - 40%), two pesticides (a -BHC - 98%, lindane 87%) and 1,2 dichlorobenzene (68%). In general, the mean concentrations of toxics in water were several orders of magnitude lower than those in sediment.

Marsalek, J. and H.O. Schroeter. 1984. Loadings of selected toxic substances in urban runoff in the Canadian Great Lakes Basin. Unpublished Report, Hydraulics Division, Canada Centre for Inland Waters, Burlington. May 1984.

The annual loadings of 51 persistent toxic substances in urban runoff in the Canadian Great Lakes Basin have been estimated from field data on toxics concentrations and calculated annual volumes of runoff and solids loadings. It was estimated that the total runoff from fully developed parts of urban centres in the basin is almost 600 million m^3 annually. The highest volume is produced in the Lake Ontario sub-basin (62% of the total). It was further calculated that this volume of runoff transports about 70,000 tonnes of solids annually. Open (undeveloped) land under municipal control may contribute another 1650 million m^3 of runoff and 20,000 tonnes of solids annually. The report provides data for toxics loadings in various parts in Ontario and appendices to the report provide annual mean precipitation for numerous urban areas and their estimated loadings of pollutants.

Meeks R.L. 1969. The effect of drawdown date on wetland plant succession. J. Wildl. Manage. 33:817-821.

A seven year study was started in 1956 to determine the effect of drawdown date on plant succession in marshes. An 80 acre marsh was diked into four units, one of which was drained yearly in mid-March, one in mid-April, one in mid-May and one in mid-June. All the units were reflooded during September. Plant succession followed the same general trend in all units, going from semi-aquatic species to predominantly annual weeds. Fewer years were required with early drawdowns for annual weeds to replace semi-aquatic species. The May drawdown unit had the best plant associations for wildlife after 7 seasons. Draining during mid to late May should allow muskrats to raise two litters without interruption, and not interfere with duck nesting.

Middlebrooks, E.J. 1987. Research and development needs for utilization of aquatic plants for water treatment and resource recovery - engineering status. Pp. 1009-1010. *in* Aquatic Plants for Water Treatment and Resource Recovery. (Reddy K.R. and W.H. Smith eds.). Magnolia Publishing Inc., Orlando Florida.

This brief conference statement outlines deficiencies in knowledge which need to be addressed to design better constructed wetlands. Basic hydrologic information beyond inflow and outflow values are not available, and what happens within the depth profile of a wetland is not clearly understood. The author argues for better monitoring of constructed wetlands to provide this essential data base.

Millar, J.B. 1971. Shoreline-area ratio as a factor in rate of water loss from small sloughs. J. Hydrology 14:259-284.

Data collected in Saskatchewan established that the rate of water loss from small sloughs varies directly with the length of shoreline per unit area and, therefore, inversely with the size of individual sloughs. Daily rates of shoreline related seepage loss to groundwater was estimated at .05-.10 cm/305 m (0.02-0.04 in/1000 feet) of shoreline on heavy clay and .17 cm (0.07 in) on sandy lacustrine material and medium textured glacial till. Up to 60-80% of the shoreline-related water loss was attributed to transpiration by phreatophytic vegetation and evaporation from the soil surface. On the average, shoreline-related water loss accounts for 60% or more of total water loss in sloughs 0.04 ha (0.10 acres) or less in size and not more than 30-35% of total loss in sloughs larger than .4 ha (1 acre).

Millar, J.B. 1973. Vegetation changes in shallow marsh wetlands under improving moisture regime. Can. J. Bot. 51:1443-1457.

Changes in species composition and plant cover were studied in relation to moisture regime over a 10 year period in 71 shallow marshes in the grassland and parkland regions of Saskatchewan. Decreases in density of the shallow marsh emergents *Polygonum coccineum*, *Carex atherodes*, *Scolochloa festucacea*, and *Eleocharis palustris* occurred with greater-than-normal water depth at the start of the growing season, but two or more years of continuous flooding were required to eliminate emergent cover completely and convert the wetland to open water. Repeated autumn reflooding also resulted in complete elimination of emergent species. Species composition of rooted submergents in a wetland can be used as an indicator of its moisture regime.

Miller, G. 1989. Use of artificial cattail marshes to treat sewage in northern Ontario, Canada. Pp. 636-642. *in* Constructed wetlands for wastewater treatment: municipal, industrial, and agricultural. (D.A. Hammer ed.). Lewis Publishers Inc., Chelsea, Michigan.

A cattail marsh was constructed at Cochrane, northern Ontario to determine whether such a marsh could deal with municipal sewage throughout the year. Plot loading was approximately 0.20L/s (170 m^3/ha/day, 19.0 mm/day) of raw sewage. Cattails were obtained from a nearby wetland area, and shoots with a 5 cm rhizome were planted at one metre intervals. A year later the marsh was completely colonized and other species such as bulrush (*Scirpus*) and smartweed (*Polygonum*) had invaded the wetland. The marsh was covered with snow and ice from the first week in November until the second week in April. For the most part the marsh treated the sewage very well. However, certain monitoring criteria are questioned, such as bacterial counts and BOD, for it was determined that other bacteria might also be present which were not deleterious and that much of the BOD in the marsh outflow might be due to plankton and breakdown of marsh organisms. The hydrology of the wetland indicated that significant amounts of water were lost either by evapotranspiration or by exfiltration.

National Wetlands Working Group. 1988. Wetlands of Canada. Ecological Land Classification Series No. 24. Sustainable Development Branch, Environment Canada, Ottawa. 452 pp.

This book provides a comprehensive guide to the wetlands of Canada. The contents include factors influencing wetland development and a classification of wetlands. Wetlands of the various regions are described including salt marshes. A section is provided on wetland utilization in Canada.

Neil J.H. and J.T Graham. 1989. The evaluation of native marsh plants for the treatment of domestic sewage. Environment Ontario, Water Resources Branch. 48 pp.

Three species of emergent aquatic plants were compared for their ability to treat domestic sewage in an artificial marsh environment. The species evaluated were narrow leaf cattail (*Typha angustifolia*), bulrush (*Scirpus validus*), and common reed (*Phragmites australis*). Monoculture stands of each species were established in separate steel enclosures and exposed to partially treated sewage lagoon effluent. Removal of phosphorus and nitrogen was approximately 75% during the first summer. During the second summer removal rates declined to around 60%. Good reductions of faecal organisms were provided by all species throughout the trials. Winter treatment declined for suspended solids, TKN, and ammonia. Overall poorest treatment in both years was by *Typha*. Duckweed was evaluated in a polishing cell in the second year and provided additional removal of ammonia, TKN, P, and other constituents. The presence of duckweed resulted in high levels of dissolved oxygen.

Oberts, G.L. 1977. Water quality effects of potential best management practises: a literature review. Technical Bulletin No. 97, Madison: Department of Natural Resources. 24 pp.

This review paper summarizes literature up to 1977. It includes BMPs in relation to source control, increased infiltration, retention of runoff, reduction of erosion, reduction of contaminant deposition, and removal of contaminants. Control of water in collection systems involves reduction of in-channel erosion, increase of runoff water infiltration, storage of runoff and removal of contaminants from the system. A final section deals with types of discharge treatment including physical, chemical and biological methods.

Odum, W.E. 1987. Research and development needs for utilization of aquatic plants for water treatment and resource recovery - ecological considerations. Pp. 1016-1018. *in* Aquatic Plants for Water Treatment and Resource Recovery. (Reddy K.R. and W.H. Smith eds.). Magnolia Publishing Inc., Orlando Florida.

The author suggests that considerably more research is required to determine how wetlands operate in improving water quality. The design of complex wetlands in which many plants are involved should be investigated together with finding ways to maintain plant and animal diversity. Knowledge about the design of constructed wetlands for wildlife is important and little information is available about this area. He concludes by exhorting scientists to study the ecology of constructed wetlands.

Ogawa, H. and J.W. Male. 1985. Simulating the flood mitigation role of wetlands. J. Water Resourc. Plan. Manage. 112:114-128.

This paper presents a theoretical simulation of the effect of wetland removal from parts of a watershed and the impact that this has on water storage capability of the wetland. The authors suggest that encroachment on 25% of a wetland area would have only minimal impact on flows. They also indicate that downstream main-stem wetlands were found to be more effective in reducing downstream flooding than upstream wetlands.

Ontario Ministry of Municipal Affairs. 1989. Wetlands, a proposed policy statement of the Government of Ontario issued for public review. 6 pp.

This proposed policy provides a background of the importance of wetlands in Ontario and why new policies must be formulated. Definitions are provided. General policies on how government bodies and agencies will approach the protection of important wetlands is suggested. Also the process of implementation of wetlands policies is given.

Parsons, J.D. and R.E. Aufmuth. 1990. Wetlands: an achievable necessity. Pp. 149-153. 1990 National Symposium on Mining, University of Kentucky.

The role of society in the modification of wetlands must be described and measured in relation to their important biological functions. Society must deal with the environmental effects of its activity. It is necessary to develop an overview acceptable to the many competing interests in society. The focus should initially be on activities which take place directly in a wetlands environment. Next, attention to activities occurring in riparian and upland areas which impact wetlands. In all cases the significance of the impact will depend on the magnitude, rate, and duration of the wetland modification and to the numbers and types of space-related environmental values affected.

Peverly, J.H. 1985. Element accumulation and release by macrophytes in a wetland stream. J. Environ. Qual. 14:137-143.

Aquatic macrophyte growth was measured seasonally in relation to element accumulation in Oak Orchard Creek, New York. The stream drained cultivated areas and ran into undisturbed wetland areas downstream. The stream flowed over calcareous soils and was enriched with N, P, and K in both water and sediments. Plant biomass was greatest in July and consisted mostly of waterweed (*Elodea canadensis*) and curly pondweed (*Potamogeton crispus*). Element concentrations in

plant tissues were above limiting levels and showed no definite relationship to season or species, although instream emergents showed a fall decrease in major nutrients. Potential contributions of major nutrients to the creek from plant senescence that occurred instream ranged from 10% to 100% in summer and fall. However, this contribution is 1% to 2% of total annual stream nutrient load.

Portier, R.J. and S.J. Palmer. 1989. Wetlands microbiology: form, function and processes. Pp. 89-105. *in* Constructed wetlands for wastewater treatment: municipal, industrial, and agricultural. (D.A. Hammer ed.). Lewis Publishers Inc., Chelsea, Michigan.

This review article describes the basic structures of organic compounds and how they can be broken down into simpler organic compounds in wetlands systems. Bacteria of the following genera are important in microbial degradation: *Pseudomonas, Myobacterium, Acinetobacter, Arthrobacter, Bacillus, Nocardia.* Bacteria generally live under oligotrophic conditions and exist in resting conditions until suitable organic compounds are available. A wide variety of species under differing environmental conditions can result in the biodegradation of many "artificially produced" organic compounds.

Prescot, G.W. 1980. How to Know the Aquatic Plants. Wm. Brown Company, Dubuque, Iowa. 158 pp.

A key to the aquatic plants of North America. This book provides a simple key to the plants and a small amount of ecological information on some species. It is a useful guide when surveying wetlands.

Pullin B.P. and D.A.Hammer. 1991. Aquatic plants improve wastewater treatment. Water Environment and Technology. 3:36-40.

This article provides information on the use of aquatic emergents in two constructed wetlands in Kentucky. Cattail *(Typha latifolia)*, and (*T. angustifolia*), soft-stem bulrush (*Scirpus validus)* and woolgrass (*S. cyperinus*) were used to quantitatively assess species differences related to the removal of TSS, BOD, N, P, from primary treated wastewater. The constructed wetlands consisted of one pond, one meadow and two parallel marshes each measuring 14.9 m X 121.9 m. One had a crushed limestone base to encourage subsurface flow and the other native soil to encourage surface flow. The system was sized for an average flow of 0.048 m^3/s and receives effluent from a 6.4 hectare lagoon. Vegetation was sampled in all the marshes and samples divided into substrate portion, within water column portion and above water column portion. The results of the marshes suggest that *S. cyperinus* had the highest

root mass and *S. validus* had the highest stem surface area of the four wetland plant species. Because both attributes are important to microbial habitat, one or both of these species may be the best candidates for constructed wetlands wastewater treatment systems. However, neither is as tolerant of poor water quality conditions as *Typha*, and neither may be able to withstand higher loading conditions.

Richardson, A.H. 1974. Conservation by the people: the history of the conservation movement in Ontario to 1970. University of Toronto Press. 154 pp.

This informative book provides a historical account of the conservation movement in Ontario. Chapters outline its function as an agency dealing with floodlands and the development of dams and waterway structures to reduce the frequency and severity of flood events. Further chapters describe its role in recreation, hunting, fishing and its influence on farming practice in southern Ontario. A recognition of the value of wildlife and its integral part of our life provides a focus for the developing shift in the philosophy and mandate of the Authorities.

Richardson, C.J. 1985. Mechanisms controlling phosphorus retention capacity in freshwater wetlands. Science. 228:1424-1427.

A comparison between the phosphorus retaining capacities of wetland and terrestrial ecosystems was studied. The study found that although wetlands may contain large quantities of stored phosphorus, this is due to accumulation over time. For new wetlands, phosphorus retention is initially very high, but after a few years the loss of phosphorus in outflow water increases markedly due to the decay of vegetation. Therefore wetlands cannot be assumed to function in the long term as sinks for phosphorus. Terrestrial soils provide a much larger sink for phosphorus than wetlands.

Richardson, C.J. and J.A. Davis. 1987. Natural and artificial wetland ecosystems: ecological opportunities and limitations. Pp. 819-854. *in* Aquatic Plants for Water Treatment and Resource Recovery. (K.R. Reddy and W.H. Smith eds). Magnolia Publishing Inc., Orlando, Florida.

Natural wetlands offer opportunities to reduce the amounts of nutrients, suspended solids and BOD from municipal wastewaters. However, the efficiency of wetlands decreases rapidly due to accumulation of nutrients and the changes to natural wetlands may be significant. The article provides detailed information on reduction rates in relation to time for major contaminants. Artificial wetlands may have greater potential than natural wetlands because they require less space, are easier to control hydrologically, and show good BOD, SS and N removal. They have relatively poor

P removal unless water penetrates the soil and aeration is increased. Management guidelines based on ecological principles are recommended.

Schneller-McDonald, K., L.S. Ischinger and G.T. Auble. 1990. Wetland creation and restoration: description and summary of the literature. U.S. Fish Wildl. Serv. Biol. Rep. 90:198 pp.

This is an annotated bibliography of papers dealing with the creation and restoration of wetlands. The text lists 1100 records with a good coverage of the technical and semi-technical literature.

Sather J.H. and R.D. Smith. 1984. An overview of major wetland functions and values. Fish and Wildlife Service. Washington. FWS/OBS-84/18. 69 pp.

This is a precis of the literature up to 1984 and provides summaries of the following subject areas: hydrology, water quality, food chain support/nutrient cycling/ habitat, socio-economic. Each section has its own bibliography.

Schueler, T.R. 1987. Controlling urban runoff: a practical manual for planning and designing urban BMPs. Metropolitan Washington Council of Governments. Washington, D.C. 275 pp.

This manual provides detailed information for engineers and site planners on the planning and design of BMPs to protect streams and remove contaminants from urban waters. It contains methods for estimating pollutant exports from development sites and suggests the methods for selecting the best BMP. Details of seven BMPs in the Washington area are described. They are: extended detention ponds, wet ponds, infiltration basins and trenches, porous pavement, water quality inlets and vegetative practices. Each BMP is reviewed in terms of pollutant removal, physical feasibility, costs, maintenance requirements, and impacts to the environment and adjacent communities.

Silker, T.H. 1948. Planting of water tolerant trees along margins of fluctuating level reservoirs. Iowa State J. Sci. 22:431-447.

This article discusses tree planting along the edges of reservoirs and other areas exposed to periodic inundation. Data on survival, height, and adaptation of trees to changing water tables and to soil and groundcover conditions were obtained for five to twelve year old plantings. Details on the success of the following tree species are provided: baldcypress (*Taxodium distichium*), tupelo (*Nyssa aquatica*), sweet or red

gum (*Liquidambar styraciflua*), green ash (*Fraxinus pennsylvanicus*), water oak (*Quercus nigra*), willow oak (*Quercus phellos*), southern white cedar (*Chaemaecyparis thyoides*) and sycamore (*Platanus occidentalis*).

Sloey, W.E., F.L. Spangler and C.W. Fetter. 1978. Management of freshwater wetlands for nutrient assimilation. Pp. 321-340. *in* Freshwater Wetlands: Ecological Processes and Management Potential. (Good R.E., D.F. Whigham and R.L. Simpson eds.). Academic Press.

Wetlands in Europe and North America have been used to remove nutrients from sewage waste water. Denitrification may remove 3.5 kg N ha day and as much as 20 g P/m^2 per growing season. However, much of the nutrients may be released between growing seasons. Plant harvesting after the growing season only removes a small part of the trapped nutrients, the rest is held by underground parts and microbial components. Some wetlands which have been used for wastewater treatment already show undesirable changes. Careful monitoring of the biota is recommended. Artificial wetlands and peat filters offer alternatives to other treatment methods and do not endanger natural wetlands.

Smith, L.M. and J.A. Kadlec. 1983. Seed banks and their role during drawdown of a North American marsh. Journal of Applied Ecology. 20:673-684.

The size and species compositions of seed banks present in small cores of substrate from six different types of vegetated marsh in Utah were tested for germination in a greenhouse experiment. The six types of marsh were characterized by the following dominant species: *Typha* spp., *Scirpus acutus*, *S. maritimus*, *Distichlis spicata*, *Phragmites australis* and open water. More species germinated in the moist soil treatment than in the submerged water treatment. Open water had fewer species germinate and low seedling densities. As water levels fall, more mudbank species germinate than emergent ones. Where saline soils are present or salinity presents a problem a small covering of water over the generating marsh will help keep salinity low and facilitate germination.

Snell, E.A. 1989. Recent wetland losses in southern Ontario. Pp. 183-197 *in* Wetlands, inertia or momentum. (M.J. Bardecki and N. Patterson eds). Federation of Ontario Naturalists, Don Mills, Ontario.

From 1967 to 1982, 5.2% of the wetland area south of the Precambrian Shield was converted to other land uses. The loss was greater in western Ontario than eastern. The highest rate was in Lambton County (30%). Conversion of land for agricultural purposes accounted for 80% of the loss, while loss to cottages accounted for only

5%, though this was a significant factor affecting lakeshore wetlands in central Ontario. The depressed farm economy since 1982 is probably responsible for a reduction in the rate of loss of wetlands.

Spangler, F.L., C.W. Fetter and W.E. Sloey. 1977. Phosphorus accumulation - discharge cycles in marshes. Water Resources Bulletin. 13:1191-1201.

Phosphorus removal by natural and artificial marshes was studied in Wisconsin. Phosphorus removal ranged from zero to 64% and removals in the 35% range were common. Much of the phosphorus is deposited in the sediments of unharvestable parts of the plants such as the rhizomes, and only about 6% of the phosphorus went into above ground vegetative parts. Although phosphorus is bound during the growing season it may be lost in effluent waters during large rain events in the fall or spring. Potential methods for capturing this phosphorus rich water include using it for irrigation or passing it through regular water treatment facilities.

Stewart, D. 1990. Flushed with Pride. Smithsonian. 21:174-179.

This light hearted article describes the development of marshes to treat the sewage of Arcata, California. The system of marshes has been built to handle domestic sewage, which is subject to settling tanks and is then fed into the series of marshes. Trails, trees and park benches abound and the place has become a mecca for interested bird watchers and municipal engineers. The water is so clean from the outflow that salmon may be introduced in the near future. The local residents have been involved in the project and take pride in their productive wetlands.

Stinson, M.D. and D.L. Eaton. 1983. Concentrations of lead, cadmium, mercury, and copper in the crayfish (*Pacifasticus leniusculus*) obtained from a lake receiving urban runoff. Arch. Environ. Contam. Toxicol. 12:693-700.

Commercially caught crayfish were placed in a municipal lake below a combined sewer outfall associated with elevated sediment/heavy metal levels. Abdominal muscle, viscera, and exoskeleton were tested for lead, cadmium, mercury and copper. They were compared with controls. Results indicated that 1) mercury accumulated in muscle, and highest levels for cadmium were in the viscera and for lead in the exoskeleton, 2) copper levels are well regulated by the crayfish, 3) visceral concentrations of cadmium, copper and lead were higher and more variable than muscle values. The levels of heavy metals accumulated would not indicate a health hazard if the crayfish were consumed by people.

Stockdale, E.C. 1986a. Viability of freshwater wetlands for urban surface water management and nonpoint pollution control: an annotated bibliography. Washington State, Department of Ecology. 106 pp.

This annotated bibliography lists 234 technical and semi-technical papers on various aspects of wetlands and their use to control urban stormwaters and non-point pollution control. Most of the literature relates to the use of wetlands for the treatment of secondary sewage effluent.

Stockdale, E.C. 1986b. The use of wetlands for stormwater management and nonpoint pollution control: a review of the literature. State of Washington, Department of Ecology. 24 pp.

Many wetlands receive surface runoff from adjacent lands. In urban areas much of this runoff is from impervious surfaces contaminated with heavy metals, nutrients, oils, greases and other pollutants. Traditionally urban stormwater management has concentrated on quantity control rather than quality control. The majority of information in the literature relates to the use of wetlands for treatment of sewage effluents. However, some researchers have shown that the characteristics of partly treated municipal waste is similar to that of urban runoff and that therefore the research findings from these studies are applicable to management of urban stormwater quality.

Although the short term advantages of using wetlands for quality enhancement has been demonstrated, there is a paucity of information related to the long term sustainable use of wetlands for quality control. Where wastewaters have been applied to natural wetlands over long periods of years, definite deterioration in terms of community structure has been noted. However, some wetlands have not shown any demonstrable effects. The need for further research in this area is discussed.

Tchobanoglous, G., R. Stowell, R. Ludwig, J. Colt and A. Knight. 1979. The use of aquatic plants and animals for the treatment of wastewater: an overview. Pp. 35-55. *in* Aquaculture systems for wastewater treatment: seminar proceedings and engineering assessment. (R.K. Bastian and S.C. Reed, eds.) U.S. Environmental Protection Agency, Washington, D.C.

The paper provides an overview of the differences between conventional treatment of wastewater and the use of plants for wastewater treatment. The fundamental difference being the rapid treatment in a highly managed environment in the former and slower treatment with less control in the latter. Conventional systems require more construction and mechanization while systems utilizing plants require more land. The authors provide details of the concentrations of wastewater constituents

before and after treatment. A list of aquatic plants and animals is provided detailing their function within an aquatic processing unit. They discuss the types of contamination present in wastewaters and concerns related to their treatment.

Tuovila, B.J. et al. 1987. An evaluation of the Lake Jackson filter system and artificial marsh on nutrient and particulate removal from stormwater runoff. Pp 271-278. *in* Aquatic Plants for Water Treatment and Resource Recovery. (K.R. Reddy and W.H. Smith eds.). Magnolia Publishing Inc., Orlando, Florida.

This paper provides values of efficiencies of wetlands in removing contaminants from water. The systems remove 95% of suspended solid load, 75% of total nitrogen, 37% of ammonia, 70% of nitrate, 75% of nitrite, 90% of total phosphorus, 53% of unfiltered phosphorus and 78% of filtered phosphorus.

U.S. EPA. 1983. Final report of the nationwide urban runoff program. EPA publication.

This comprehensive report summarizes information from across the United States. The problems of stormwater management are outlined, and are then dealt with in detail. The report provides a useful compendium of information about BMPs in urban areas and ways of controlling pollution. It does not go into the use of wetlands for stormwater management though it suggests that when sufficient material has been collected the team may produce design criteria.

Vandenberg, A. 1986. A Physical Model of Vertical Infiltration, Drain Discharge and Surface Runoff. National Hydrology Research Institute. Bull. No 137.

This paper provides a technical model for calculating effects of drainage on water runoff flows. A change in the nature of the soil has a marked effect on the reservoir capabilities of the soil. An increasing amount of clay reduces the holding capacity of the soil and its ability to store water between major rain events.

Vanderberg, A. 1989. A physical model of vertical integration, drain discharge and surface runoff for layered soils. National Hydrology Research Institute, Saskatoon. No. 42.

The elements of the hydrologic cycle and their interrelationships which are directly influenced by soil and surface drainage improvements are identified. A model for this particular cycle is constructed permitting the assessment of the effect of drainage improvement on the total discharge from a drained plot for a given precipitation

input. Total discharge is composed of surface runoff and drain discharge. Particular emphasis is placed on the soil moisture component, infiltration and percolation to the ground water table. The effect of inhomogeneities in the soil profile on the shape and timing of the discharge is illustrated with a few examples.

Voigts, D.K. 1976. Aquatic invertebrate abundance in relation to changing marsh vegetation. American Midland Naturalist. 95:313-322.

The relationship between invertebrate populations and vegetative cover was studied in several Iowa marshes during the peak of the avian nesting season. Shallow water with emergent and floating dead vegetation produced the most isopods, planorbid snails and physid snails. Physid snails had another abundance peak in areas where submerged plants were found below dense free-floating plants. Midges reached greatest abundance in more open habitats somewhat protected from wind. Amphipods were the most numerous invertebrate taxa and were most abundant in dense beds of submerged vegetation. Cladocera and copepods were the most common in quiet pools with little vegetation. Total invertebrate abundance increased as the emergent vegetation was replaced by submerged vegetation, but maximum numbers occurred where beds of submerged vegetation were interspersed with stands of emergent vegetation. It is suggested that marsh birds are attracted to marshes that produce the most invertebrates.

Watson, J.T., F.D. Diodato and M. Lauch. 1987. Design and performance of the artificial wetlands wastewater treatment plant at Iselin, Pennsylvania. Pp. 263-270. *in* Aquatic Plants for Water Treatment and Resource Recovery. (K.R. Ready and W.H. Smith eds.). Magnolia Publishing Inc., Orlando, Florida.

The Tennessee Valley Authority is demonstrating the use of wetlands for treatment of municipal wastewater to meet the National Pollutant Discharge Elimination System limitations. The system is modified after the Iselin project in Pennsylvania. It consists of an aerated pond, a cattail marsh, a stabilization pond and a reed canary grass meadow. Average effluent concentrations for the first 31 months of operation are BOD 7.4 mg/L, SS 19 mg/L, NH_4 -N 3.3 mg/L, total P 2.6 mg/L and faecal coliform 150/100 mL.

Watson, J.T., S.C.Reed, R.H. Kadlec, R.K. Knight and A.E. Whitehouse. 1989. Performance expectations and loading rates for constructed wetlands. Pp 319-351. *in* Constructed wetlands for wastewater treatment: municipal, industrial, and agricultural. (D.A. Hammer ed). Lewis Publishers Inc., Chelsea, Michigan.

An excellent article providing a large amount of valuable detail for the construction of wetland systems. The account details municipal and acid mine waste water treatment and identifies surface and subsurface treatment techniques. Subsurface treatment requires a porous gravel substrate. A table provides a comparison of removal efficiencies for major contaminants from different test sites. Different plants achieve different removal rates, for example the bulrush removed 94% of applied nitrogen while reeds, cattails and unvegetated beds achieved 78%, 28% and 11%, respectively. Most systems are designed with a slope of 1%. Surface flow systems are typically loaded less than subsurface. Loading rates for municipal and mine wastes are provided.

Weller, M.W. 1975. Studies of cattail in relation to management for marsh wildlife. Iowa State Journal of Research. 49:383-412.

Experimental studies on the common cattail (*Typha latifolia*) and a robust hybrid (*T. latifolia x T. angustifolia*) were conducted in the laboratory and marshes in northwestern Iowa. Germination rates were inverse to water depth, with maximum germination in one inch of water. Hybrids grew taller than common cattail, but had stems of smaller average diameter. Rhizome shoot production was inverse to water depth. Flooding of cut stems for one year killed the plants. Maximum bird populations required maintenance of a 1:1 cover-water ratio with interconnected and well dispersed pools larger than 30 feet in diameter. Water level manipulation and management of muskrat populations were considered the most natural, effective, and least expensive means of providing such cover.

Weller, M.W. 1978. Management of Freshwater Marshes for Wildlife. Pp. 267-284. *in* Freshwater Wetlands. (R. Good, D. Whigham and R. Simpson, eds.). Academic Press, New York.

This is an overview of freshwater management for wildlife. Topics include (1) the structure of marshes and their use by wildlife, (2) marsh succession, (3) influences of water depth and muskrats on vegetation, (4) the use of natural processes in marsh management (e.g. water-level manipulation, system management, grazing, burning, modification of water salinity), (5) artificial procedures for modifying marshes (e.g. cutting, herbicides, artificial nest sites) and (6) sociological aspects of marsh management.

Weller, M.W. 1988. Issues and approaches in assessing cumulative impacts on waterbird habitat in wetlands. Environmental Management. 12:695-701.

Wetlands are attractive to vertebrates because of their abundant nutrient resources and habitat diversity. Because they are conspicuous, vertebrates are commonly used as indicators of changes in wetlands. Such impacts take place at the landscape level. Vertebrates use wetlands differently according to age, sex, season and geographic location and evaluations based on isolated observations can result in biased or erroneous conclusions. Several approaches for estimating bird habitat losses are derived from population curves based on natural and experimentally induced population fluctuations. Additional research needs and experimental approaches are identified for addressing cumulative impacts on wildlife habitat values.

Wenck, N.C. 1981. Wetlands and organic soils for the control of urban stormwater. Pp. 227-240. *in* Selected Proc. Midwest Conference on Wetland Values and Management. (B. Richardson ed.). St. Paul, MN.

This article reviews three systems installed in Minnesota to control urban stormwater. The article is a mix of data of phosphorus loadings from different types of urban environment and information about design characteristics of constructed wetlands to deal with problems of water quality. A 10 acre marsh is used to deal with urban runoff and treated wastewater. The marsh is allowed to fill with 15 acre feet of combined stormwater and treated wastewater during a 1 1/2 day period. The water is held for a period of four days and allowed to discharge over a 1 1/2 day period. The wetland is then rested for 3 days before the fill cycle is started again.

Whigham, D.F., C. Chitterling and B. Palmer. 1988. Impacts of freshwater wetlands on water quality: a landscape perspective. Environmental Management. 12:663-671.

Riparian areas that border upland streams appear to be important sites for nitrogen processing and retention of large sized sediment particles. Fine particles associated with phosphorus retention are retained in downstream wetlands. Riverine systems may play an important role in nutrient cycles, primarily during flood events. Lacustrine wetlands appear to have least impact on water quality due to the small ratio of vegetated surface to open water.

Wieder, K.R., M.N. Linton and K.P. Heston. 1990. Laboratory mesocosm of Fe, Al, Mn, Ca and Mg dynamics in wetlands exposed to synthetic acid coal mine drainage. Water, Air and Soil Pollution. 51:181-196.

This paper describes a laboratory duplication of the ability of wetlands to retain elements which one would expect in acid mine drainage. Wetland analogues were made containing a) *Sphagnum* + *Typha*, b) *Sphagnum*, c) bare peat. Simulated mine waste water was run through each system. Iron is concentrated in each of the wetland types and appears to reach saturation at 286.7 mg g^{-1} at week 14. The other metals were not significantly reduced in concentration by passage through the wetland. The study raises questions about many field studies in which aspects of water addition through groundwater and rain are not controlled and distort the purported efficiency of the wetland at removing metals.

Wile, I., G. Palmateer and G. Miller. 1981. Use of artificial wetlands for wastewater treatment. Pp. 255-271. *in* Selected Proc. Midwest Conference on Wetland Values and Management. (B. Richardson ed.). St. Paul, MN.

The wastewater treatment facility at Listowel in Ontario is described. The facility consists of five separate systems and a small control marsh for monitoring evapotranspiration. The marshes were planted with cattails. High levels of nutrient removal occurred through the summer months, together with reductions in bacterial counts and suspended solids. During the winter the system did not work so well. Details are provided of the seasonal fluctuations in monitored parameters.

Winger, P.V. 1986. Forested wetlands of the southeast: review of major characteristics and role in maintaining water quality. U.S. Fish and Wildlife Service Resource Publication. 163:16 pp.

Forested wetlands in the river valleys of the southeast of the USA are highly productive ecosystems. The wetlands are characterised by distinct hydrologic cycles involving flooding and drawdown periods. This results in changes in the aerobic nature of the soil and variation in soil chemistry which are important in the process of maintaining water quality. The periodic alteration between anaerobic flooded and aerobic dry periods facilitates the assimilation of nutrients and organic matter, hastens the degradation of pesticides and decreases the availability of heavy metals.